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DESCRIPTIONS: A BASIS FOR MEMORY ACQUISITION AND RETRIEVAL

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This paper postulates that the processes of memory retrieval operate upon descriptions which provide an initial specification of the information being sought, guide the memory search process, and help determine the criteria for verification of whatever information is retrieved. Descriptions provide a basis for a set of iterative processes for both memory acquisition and retrieval. In acquisition, memory descriptions and records can be elaborated in ways intended to aid later retrieval. In retrieval, the initial description of the information sought can be modified as intermediate information becomes available during the retrieval cycle. Two important aspects of memory descriptions are discriminability and recoverability: their ability to discriminate among all possible records in memory and the likelihood that they can be recovered at the time retrieval is required. An analysis using descriptions provides a consistent interpretation of a number of different memory phenomena, including depth of processing, some interference phenomena, accessibility and encoding specificity, mnemonics, and some properties of naturalistic recall.

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Descriptions:

A Basis for Memory Acquisition and Retrieval

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Our goal is to understand the functional mechanisms of memory storage and retrieval. In this paper we direct our concern towards how a person recovers information that was acquired previously. This concern leads to several questions: How does the person know what information is to be retrieved? How is that information specified? How is the retrieved information verified as indeed being the information sought? What are the interactions between the encoding operations done at the time of storage and the processing performed at the time of retrieval?

We propose that retrieval depends upon the formation of a description of the information sought. We suggest that the success or failure of memory retrieval depends upon the ability to encode information at the time of storage in such a way that an appropriate description can be constructed at the time retrieval is desired.

We suppose that information in memory is encoded into structured units, called records. The particular record being sought we call the target record. A description is any specification of the target record intended to specify it to the retrieval mechanisms. There are many possible descriptions of any given record, and the efficacy for retrieval of a particular description is highly dependent upon context: both the context of the events surrounding the encoding at storage and the context provided by whatever other records exist in memory during retrieval. A description can specify some of the contents of the target record, or the sequence of retrieval operations that might lead to the target record. A description could also specify other records that are believed to be closely enough associated with the target record that once they are found, the target is more likely to be recovered.

A useful analogy to the use of descriptions in memory specification is the verbal communication task in which one person must get another to do something using only verbal descriptions. Consider a situation in which person A stands before a tabletop that has a number of wooden blocks on it, the blocks being of various shapes, sizes, and colors. Person A must tell Person B to pick up various blocks. Only verbal communication is allowed (the situation is taken from a standard experimental paradigm in the study of communication, for example, the studies of Olson, 1970, and Osgood, 1971). How the block is specified depends upon what other blocks are present. A block can be described by its location ("the block in the upper left-hand corner"); by its shape ("the U-shaped block"); by color ("the red one"); or by its position relative to others ("the block between the triangular one and the red pyramid"). A block can be described by its role in past events ("the block you moved first"). Moreover, having referred to a particular block by a long description, in the future it can be specified by a much briefer one, such as "the red one," the big one," or even just "it," under the assumption that the description now applies not to the entire tabletop, but only to those blocks most recently described or operated upon.

The verbal communication task differs from the memory retrieval task in several ways. First, in memory retrieval, the specification is not limited to verbal descriptions, but can be in any form relevant to memory structures. Second, the memory retrieval problem is complex because, unlike the situation on the table, all possible records of memory are not visible at any given time. Thus, the description must be formed by assuming the properties of the target record. If the assumption proves false, the results of the initial memory retrieval can be used to help discover characteristics of the other records and, therefore, something about the nature of the specification that is required. Finally, the retrieval situation is often such that one does not really know just what record is being sought. Rather, one has some purpose, some gap of knowledge which must be filled by the target. In this case, the specification must be based upon the current need for information and the assumed properties of the target record. Retrieved records are evaluated according to how well they fulfill the need.

Descriptions and Memory Records

A memory record of something contains a description of that thing, created with the biases present at the time of the encoding and the memory records that existed at that time to guide the interpretations. A "description" is an interpretation. At the time of memory acquisition, descriptions play the role of an intermediary between the perception and the formation of a memory record. At the time of retrieval, descriptions play the role of an intermediary between the specification of what is being sought from memory and the retrieval processes involved in ferreting out the appropriate record. Note that a major distinction between descriptions and records is one of function: a memory record is a unit within the data base of the memory system that serves as the representation of knowledge about something. A record can also serve the function of a description, either guiding the creation of a new record or acting as an intermediary in the search for an existing one.

The Structure of Records

Memory records must have some structure and must allow for associative links among themselves. This aspect of memory has been known since the time of the early Greek art of memory. More modern work on the nature of associations indicate that if they are to be useful for guiding thought (and, especially, inference), it must be possible to differentiate the direction and the type of association. (See the discussions in Anderson & Bower, 1973; Norman, Rumelhart, & LNR, 1975; and Woods, 1975.) We further suggest that memory information is chunked. That is, information is stored such that there is a unity to the knowledge available at any time. Several aspects are available simultaneously: a record is simply that collection of aspects. So far, this is not much of an assumption. Our analyses of memory usage and our experiences with the development of formal models for the representation of information within memory indicate that more is required (Bobrow & Winograd, 1977; Norman, Rumelhart, & LNR, 1975). In particular, we believe that memory records have at least seven properties, some of which are shared with memory descriptions.[1] The seven are:

1. inheritance
2. default values
3. organizational structure
4. procedural information
5. prototypes
6. perspectives
7. further specification

The first property of records, inheritance, is a standard one for semantic network structures, but we believe it necessary for other representations as well. It provides for properties of the prototype to be "inherited" by instances of that prototype. Hence, if it is known that fish swim, it is not necessary to encode this information with every instance of fish: the information is derivable if needed through the inheritance property. The second property, default values, is related to inheritance. Basically, a default value is a specification of a particular, specific value of a feature that is assumed to apply to instances of a prototype, unless otherwise specified. Thus, all visible objects must have surface color, because this is a property of visual perception. But some classes of objects have typical values of colors. Thus, in the United States, fire engines are usually red, and so if the encoding of an instance of fire engine does not specify its color, its default value is red. Both default values and inheritance can be overridden by further specification of a record, so that a particular fire engine can be further specified as being green.

The third and fourth properties of records, organizational structure and procedural information, provide cohesiveness to knowledge, pulling together into some formal structure otherwise disparate descriptions and relationships. The properties of procedural information allow for active memory structures, with encoding of actions as well as of concepts, percepts, experiences, and ideas. In many ways these are two of the most important properties: the one being the basis for schemas and theories of organization the other the basis for the existence of sensorimotor schemas. But for our present concern with memory storage and retrieval, these are not so important.

The Structure of Descriptions

Our view of descriptions derives from earlier ideas described in Bobrow & Norman (1975) and Moore & Newell (1974), elaborated and partially implemented in the computer language KRL (Bobrow & Winograd, 1977). We suggest that three essential components of a description are the last three items on the list of properties of memory records: prototype, perspective, and further specification. Suppose the memory record for some particular event, E, is being formed. One way to begin is to identify some existing memory record as the organizational framework with which to describe E. This existing record is the prototype. The description, then, would essentially be a statement that the record sought was something like this prototype record,

further specified by whatever other information about E was available at the time. The basic encoding strategy of memory is therefore postulated to be that of identifying each new experience as a special form of some previous experience.

Any given experience will not be an exact match to a former experience. Sometimes it differs in details, sometimes in organization or point of view. The same event can be interpreted quite differently when viewed with different perspectives. This fact is incorporated into language. Thus, we have many words that refer to different viewpoints of the same event. Each of the pairs of terms chase and flee, escape and elude, buy and sell, come and go can often refer to different perspectives of the same underlying situation. We believe the same holds true for descriptions. We call a description from a specific point of view a perspective.

Specification of a perspective as a description of an event requires identifying a prototype (P) and component parts of both the event and the prototype, specifying what roles the parts of the event play with respect to the identified parts of the prototype P.

In addition to choice of a prototype and perspective, a description must further specify the elements corresponding to the component parts of the prototype. Because the prototype memory record has characteristics that may or may not apply to the event, further specification of the description is necessary. First, there may be particular aspects of E that must be specified. Second, some of the values of P may not apply to E.

A description thus may consist of a perspective which specified the prototype around which the perceptions of the item E were organized. Sometimes, Several prototypes may be required to describe E more precisely. We call this aspect of memory records multiple description.

Acquisition and Retrieval

The Acquisition Process

New information that is to be entered into memory structures can come from two sources: external and internal. That is, the new information could be an encoding of perceptual events, or it could be inferences and elaborations of the results of mental processing of material retrieved from memory. Aside from differences in immediate origin, both

situations are similar. Moreover, both usually occur in combination, with perceptual information being interpreted by means of analyses of retrieved information and mental processing of retrieved information being supplemented by analyses of sensory occurrences.

Perceptual information can be thought of as a description of sensory events, viewed from a particular perspective that is especially relevant at the moment, elaborated upon by information available through processing of the overall context. The output of the memory retrieval process (and whatever mental processes operate upon combinations of memory retrievals and perceptual input) can also be thought of as descriptions, more or less elaborated from the components provided by the individual contributors. Thus, we conceive of the starting point of the acquisition process as a set of descriptions that have become temporarily activated. If the normal short-term memory structures of the person act as the working memory system for processing, then we can consider the process of storing new information structures within memory to be that of incorporating the descriptions active in short-term memory into the data base of memory records. The subprocesses that are involved in memory acquisition are summarized in Table 1.

Table 1. The subprocesses involved in memory acquisition.

Subprocess	Input to the Subprocess	Output from the Subprocess	Comment
Perceptual processes	Sensory data Context Purposes Needs Set	Perceptual descriptions	
Memory retrieval	Context Purposes Needs Partial descriptions	Memory descriptions	Summarized in Table 2
Short-term memory	Perceptual descriptions Memory descriptions	Descriptions	A state in which working information is maintained
Elaborative processes	Descriptions from primary memory Retrieval terms from the indexing process	Descriptions	May require memory retrieval

Elaborative processes. Many memory strategies exist for encoding information in ways that are particularly efficient for later recovery. Mnemonic techniques have proven to be quite effective, and are frequently used by practitioners of the art of memory: we return to these techniques later. Much recent experimental work has concerned the efficacy of a number of different procedures that a person can perform on material at the time of storage. Such procedures are studied as elaborative procedures or integrative activities or levels of processing. All these activities share common features in providing efficient indexing of the to-be-stored material in such a way that at the time of retrieval, descriptions that are capable of guiding the

retrieval process can be recovered successfully. We return to these issues later.

The Retrieval Process

How shall we characterize the retrieval from a large memory structure? The reconstructive nature of memory is well accepted, with the normal source of the concept usually being Bartlett (1932), but good discussions can be found in other literature, such as Woodworth (1938) and James (1890). A cycle of repeated retrievals and verifications appears to be required, with the initial memory description serving as a starting point and with repeated cycles serving to modify the description of the information sought and to redirect the process until either an adequate record is recovered or the search is judged to be unsuccessful or not worthy of further effort (Norman, 1968; Shiffrin, 1970). This form of reconstructive, iterative memory retrieval requires several subprocesses. As listed in Table 2, they are: search, evaluation, retrieval specification, and failure diagnosis.

Table 2. The subprocesses of memory retrieval.

Subprocess	Input to the Subprocess	Output from the Subprocess	Comment
Retrieval specification	Purposes Needs Partial descriptions Perceptual descriptions	Target description Verification criteria	May require memory retrieval
Search	Target description	Memory records	
Evaluation	Memory records Verification criteria	Success or failure If success: terminate If failure: diagnosis	May require memory retrieval
Failure diagnosis	Information from evaluation process	Revised retrieval specification	

Search. Retrieval of information from memory structures requires some process that examines the structures and selects records thought to be relevant. We call this process search.[2]

Evaluation. Whatever information is obtained by means of the search processes must be evaluated for suitability (according to the verification criteria established by the retrieval specification). Like search, evaluation may be done in many possible ways. In earlier work on retrieval of information from short-term memory structures, where memory strength was the variable of concern, verification consisted of comparing the memory strength of retrieved items with

pre-established criteria. In the study of retrieval of information learned many years previously, Williams (1977) noticed a phenomenon he called overshoot, in which people continued the recall process even after recovery of a target item, in an apparent attempt to determine if the retrieval was consistent with the task specification. Thus, the subprocess of memory verification may require the process of memory retrieval in order to assess the suitability of the items that have been retrieved.

Failure diagnosis. If the evaluation of the recovered records is negative, there must still be determination of how to proceed with the memory retrieval process. We call this failure diagnosis and separate it from evaluation to emphasize its importance in the memory cycle. Often the information retrieved from memory is unsatisfactory, but gives evidence of approaching the desired goal. Sometimes the retrieved information can help guide future memory search. Accordingly, we believe that memory retrieval cycle can be repeated after a failure diagnosis by revising the retrieval specification (and especially the target description) and repeating the cycle of search and evaluation.

When a description is used to guide a retrieval cycle, the errors in retrieval are often informative. The retrieved records will be similar to the target record, for they share similar descriptions. These properties make access through descriptions a robust mechanism. Errors in specification, in storage, or in the retrieval mechanisms yield records that are similar to the one sought. Because a description is decomposable into meaningful parts, descriptions provide information about the target record. For some purposes, the description may provide sufficient information that the described record need not be retrieved at all. Note that a part of a memory record is a description, that part of a description is still a description, and that even partial descriptions provide information.

Retrieval specification. The starting point for the process of memory retrieval must be some specification of the information needed. As we have already mentioned, this specification can take on many forms, sometimes simply describing what purpose the sought-for material will fulfill, sometimes emphasizing the contextual information present at the time of encoding, sometimes presenting more or less complete descriptions of the information being sought, with the goal being confirmation of its aptness. Whatever the nature of the initial retrieval specification, we believe that it is used to produce two types of information: a target description and verification criteria.

Often, the determination of these requires information from memory and so may require memory retrieval.

Recoverability and Discriminability

Descriptions have two important functional properties when used as retrieval keys. First, they must discriminate among the many items within memory to be able to find the record sought. Second, the description must itself be recoverable or constructible from memory, and this may require search of memory to provide the necessary information. Thus, the retrievability of information from memory is a function of both the recoverability and discriminability of the description which serves as the retrieval key. Recoverability refers to the likelihood that an appropriate description can be recovered when the need for a particular record becomes apparent. Discriminability refers to the ability of that description to discriminate among all the possible records within the memory. [3]

Discriminability must depend upon consideration of all the items within the memory structures at the time of retrieval, including new records that might have been acquired since the time of storage. Thus, relative uniqueness of an item or of an encoding at the time of storage, particularly as measured by comparison to other items being acquired at the same time, do not provide an adequate assessment of discriminability when retrieval is to be performed with some delay following the original acquisition.

Psychological Phenomena

Descriptions in Perception

The notion that the output of perceptual processing might be a description of the scene being experienced, biased by the mental set of the perceiver and by attentional, contextual, and other factors, follows directly from numerous studies of perception. Indeed, this position has already been explicitly proposed by Rock (1975: pp. 312-315 and 426, footnote) and by Bregman (1977: especially pp. 256-261). The classic relevant study in perception is probably that of Carmichael, Hogan, & Walter (1932), who showed that reproduction of a visually presented object could be biased if at the time of the original presentation, the experimenter introduced each item by saying "The next figure resembles x," where x was one of a pair such as "eyeglasses or dumbbell," "bottle or stirrup," "curtains in a window or diamond in a rectangle." This is explicit cueing of a prototype. The results show definite influence of the suggestions. [4]

Numerous other studies in the reproduction of visually presented material seem most easily interpreted according to the notion that the percepts were encoded using a prototype as the basis for the description. Perhaps Gibson put it best:

> It has been noted that forms changed towards objects, towards the verbal descriptions made of the forms, and towards other forms perceived contiguously in time. The first two phenomena might be explained by the hypothesis that new perceptual activity in an observer takes place in terms of old perceptual habits. The third phenomenon would be due to the fact that one train of perceptual activity is modified by another if they overlap in time and if they have any elements or processes in common. (Gibson, p. 38)

Navon (1977) has argued that visual perception proceeds in a global to local fashion, with global analysis of the scene occurring first, then focussing in on more and more of the details. Thus, in the perception of a visual scene, first there is likely to be identification (description) as simply "objects," or perhaps, a "group of objects." As analysis continues, the description might be enriched by the specification of their spatial relationships with one another. Then the objects might become better differentiated and better specified. The configuration may change, and new identifications are made. All this can be done primarily by embellishments upon the existing description (with the exceptions occurring where a global description is found to be totally incorrect upon further analysis). These arguments would seem reasonable for perception in general, not just for vision.

Levels of Analysis -- Levels of Description

A description of a record must be based upon the characteristics of that record, or its context, or upon elaborations and interpretations of its meaning or form. The availability of different levels of description changes with the amount of processing resources applied to the task.

Consider the processing of newly arrived sensory information. The initial description can refer only to sensory features, for that is all that exists. Both recoverability and discriminability of this description are likely to be low, for the possible features are limited by the properties of the sensory system. Moreover, there is likely to be a very high overlap of sensory features among items, with the same features occurring over and over again.

As the analysis of newly arrived sensory information continues, progressing through the first stages of semantic analysis, to the analysis of inferences implied by the information, to elaborations upon the material, then the set of possible description terms increases enormously, thereby increasing the discriminability of the records and increasing the memory retrieval power. Note that our analysis parallels the description provided by the "levels of processing" view of memory, especially as presented in the original paper by Craik & Lockhart (1972). Note that we have added one feature by rephrasing the idea in terms of levels of descriptions: an emphasis on the encoding that occurs at the time of retrieval. Both recoverability and discriminability must be considered.

Table 3 provides a rough classification of the factors influencing discriminability of descriptions. It assumes that at the first few levels of analysis, there is a relatively stereotyped, fixed set of description terms available for describing the information being encoded. Thus, sensory information is limited to whatever is the basic set of sensory features abstracted by the sensory processes. These sets of features are likely to be common for a large variety of items, and so each feature has limited discriminability among items. As analysis continues, the number of possible descriptions increases and as the analysis becomes more enriched to consider inferential and elaborative aspects of the information, descriptions can be formulated in terms of large scale patterns in the memory data base. Thus, a visually perceived object can be described in terms of lines and angles, or as a member of a class of things, or in context, (perhaps) as a particular participant in some complex incident. If the external context is impoverished (as in an experiment) a skillful memorizer can construct some elaborate imaginary scenario in which to place the items, thus artificially creating an elaborate, large-scale pattern for encoding. Whatever the actual details of the encoding, Table 3 illustrates our classification of the component terms and the discriminability of the resulting descriptions.

Table 3. Levels of descriptions.

Level of Analysis	Form of Description	Vocabulary of Description Terms	Frequency of Term Overlap	Retrieval Discriminability
Initial sensory-perceptual	Sensory-perceptual code	Limited, fixed elements	High	Low
Meaningful	Prototypes and perspectives	Memory records	Medium	Medium
Inferential	Perspectives, defaults, further specifications	Descriptions Multiple descriptions and elaborations	Low	High
Elaborative	Multiple perspectives and prototypes New structures	Large-scale structures	Very low	Very high

Interference

When different items are coded with similar description terms, interference phenomena should be observed. The interference can be due to a lack of discrimination by the descriptions used in retrieval. Note that in the initial levels of descriptions, information arriving from different sensory modalities would normally receive quite different description terms. Hence, if information from two sensory modalities were intermixed in the same memory system, one would not expect any difficulties in discriminability, for the descriptions would not overlap. Thus, if a list of auditorally presented words were presented to a person,

followed by some visual material, the visual information would not lower the discriminability of the verbally encoded information. The resulting lack of interference would make it appear as if the different modalities each had separate memory systems, whereas in fact, it was only that separate sets of description terms were being used. The different sources of information would be confused with one another were a common coding scheme applied to them, of course. Thus, verbal coding of visual material, or visual images generated from verbal material, will cause overlapping description terms and, hence, reduced discriminability. Interestingly, these ideas lead us to predict that visually and auditorally presented material will interfere least when they receive only shallow levels of processing, most with levels that get at common meaningful aspects of the material presented. A similar discussion can be applied to other forms of interference, including both proactive and retroactive interference, and the phenomenon known as "release from PI" (Wickens, 1970).

Accessibility and Encoding Specificity

There are several different experimental paradigms that have been used to illustrate some of the problems of recovering an adequate description of the target item. Most of these paradigms are due to the work of Tulving and colleagues (especially see the review by Tulving & Thomson, 1973).

In the terms of description theory, for successful retrieval, the description must correspond to the original encoding. If information was described in one way at the time of acquisition, but in a different way at the time of retrieval, then the process of retrieval will fail because the retrieval specification leads to inappropriate descriptions and inappropriate evaluations.

In standard experimental procedures, a recall task specifies the contextual situation under which the information was acquired. This is a partial description of the original situation: the person must elaborate upon the description to the point where individual items can be recovered. Usually, these individual items were explicitly specified at the time of encoding as the material that would later be required. A recognition task usually also specifies the contextual situation of the original encoding, but in addition, presents the person being tested with test items: the person must retrieve sufficient information to confirm or disconfirm whether the test items had been experienced at the time of presentation. In both recall and

recognition, the person's task is to recover a sufficiently complete description of the original experience that the appropriate relationship between the original experience and specific memory information can be determined. Both acquisition and retrieval can be greatly affected by anything that biases the nature of the perceptual encoding. The success of the retrieval process depends upon how well the description of the information being sought matches with the description of the material that has been acquired.

It seems clear that recoverability is highly affected by the retrieval specification available at the time of retrieval. Thus, in both natural situations and in the laboratory, the initial cues available will strongly affect the success of the retrieval phase. The more specific the description of the target item, the more likely an appropriate description can be created. Too much specificity, however, can lead to an inappropriate description, thus leading to failure of retrieval. In laboratory experiments, one would normally expect that the more information provided by the experimenter, the more likely an appropriate description will be formulated. Hence, recognition tests of memory are usually more sensitive than recall tests. But it is also possible for inappropriate information to be provided, thus causing errors in the formulation of the description and leading to the retrieval of inappropriate records. Moreover, because the retrieval specification helps determine the evaluation criteria, even if the appropriate information is retrieved, it may be rejected by the evaluation process.

Mnemonics

Over many years, mnemonic strategies seem to have evolved in ways that maximize both recoverability and discriminability. We believe that one reason mnemonic systems work is because they provide systematic procedures for encoding with considerable elaborative structure the material that is to be learned. This guarantees encoding into relatively large, unique memory structures. These encoding provide high discriminability. But the strategies do more than simply provide good discriminability; mnemonic strategies are also deeply concerned with the recoverability of the encodings.

Recoverability is obtained because the encodings are performed with systematic strategies, so the user knows the starting point for regenerating the encoding. Consider one standard mnemonic strategy, the method of loci, where a familiar sequence of known locations is used as part of the

encoding of the material to be learned. In the method of loci, the starting point for the memory retrieval is given by the familiar sequence of locations. Each new description receives a strong clue to its recovery because one part of its description -- its association to a specific location -- is provided by following the well learned path through the locations. Similarly, professional mnemonists also use highly standardized, well learned key word lists for discriminable encodings and easy recoverability. With chained associations, the procedure systematically bridges from each encoding to the next successive retrieval specification. Mnemonic systems are one of the few situations where recoverability of adequate descriptions has been stressed as strongly as the discriminability of descriptions. Mnemonic systems, of course, were developed for practical use, and so systematic retrieval procedures were a natural requirement.

Some Observations of Naturalistic Recall

We have two major sources of information about recall by people in a reasonably naturalistic situation. By this, we mean that the information being recalled was either naturally acquired or the recall was a natural outcome of an attempt to recover information needed for doing some task. One source comes from the studies by Williams (1977) of how people retrieve the names of people with whom they had graduated from high school (4 to 19 years prior to the experiment). Williams required his subjects to think aloud and to describe their retrieval processes. The high school records were available with which to verify the accuracy of the reports.

A second source of information comes from our studies of how people learn complex topics. In the process of doing these studies, we have collected extensive protocols of the behavior of people attempting to retrieve information about complex topic matters to which they were exposed for several hours two-to-four weeks previously. (The topics were FLOW, a simple computer programming language, and POET, a computer system for editing manuscript texts.)[5] In these situations, the subjects often struggle for relatively long periods of time to retrieve the names of the commands which they wish to use. The protocols reveal some of the structure of the retrieval mechanisms.

The first observation is of a subject attempting to recall a command in the FLOW programming language. This protocol comes from the start of an experimental session, approximately two weeks after the subject's last exposure to

the task. The target item is the letter T, which signifies the command "Text is '...'". The subject is seated at the keyboard of the computer terminal. The protocol illustrates two things: the attempt to complete a description of the target record and the attempt to use information in the environment (the terminal keyboard) as a retrieval cue.

Subject: So all I'm trying to do is remember uh remember that. Let's see -- D is display. Hmm.

Experimenter: How are you trying to remember?

Subject: Well, the designation was closely associated with the you know, data entry, or whatever, so it should be a cognate or something like that, it should be you know, what shall I say, a mnemonic, well closely associated with the word, with the actual operation. I just can't remember the word. Hmm.

Experimenter: What are you doing now?

Subject: Still remembering. Still trying to remember.

Experimenter: (Attempting to get a description of the subject's visual search of the terminal keyboard onto the audio tape) Are you looking at the keyboard?

Subject: Yes, right.

Experimenter: What are you doing when you look at the keyboard?

Subject: I know certain keys do certain things, and I'm just running through them -- D was display (subject looks at D). ER was erase a program. Hmm. (Subject looks at E, possibly at R.) That was quit (subject looks at Q). This was jump (looks at J). Jump to -- hmm. Well, I could try some things. Is it ok if I push buttons...

(Eventually the subject did a systematic exploration of the keys on the keyboard, typing each one and watching the response on the display screen. When he got to T, the computer responded "Text is," which brought the immediate confirmation from the subject: "Text is, there we go." The use of external information as memory cues was common with our subjects.)

The next protocol is of a subject studied by Williams (1977) recalling names of high school classmates. It

illustrates continued retrieval in an attempt to get at the target item. This extended retrieval (to use Williams' terminology) is a common phenomenon as subjects attempt to elaborate their description of the target item.

> Subject: I'm trying, I'm -- ok. I was imagining the whole room and I was imagining the instruments set up and I'm trying to remember the name of this guy -- who used to do art, and he was in my 10th grade art class, which would also bring a whole lot of people too -- first on that (lots of banging and tapping). What's his name now? Let's see -- (whistle) I'm trying to -- remember his name, at his house was the first time I ever heard a Jefferson Airplane album. Umm, plays the bass guitar. Really strungout-looking dude, uh, wow.

These protocols only begin to illustrate the phenomena. We believe that these examples and our other observations are all consistent with a memory retrieval system that continues to elaborate on the description of the information sought, seeking information from the environment, from the nature of the retrieval specification, and from information retrieved from memory.

The verification process can take longer than the actual retrieval. Verification frequently requires additional retrieval of information in order to determine whether the information retrieved is consistent with the specification of the target. Thus, in the earlier protocol in which the subject reported the use of the external cue of a wheel to retrieve the name "Wheeler," the verification process revealed sufficient disconfirmatory information that the name was rejected (Williams, 1977):

> Subject: I was just looking at the wheel of, of that chair, and I was thinking of Wheeler -- Linda Wheeler? That name, I don't know if that was in my -- Linda Wheeler, that name -- Now there's a name that doesn't have a face that goes with it. I'm not even sure that -- No! That's not in high school. That's here. That's here in college. Scratch that. That was Lynn Wheeler. She was a roommate of one of the friends I have here on campus. So that's out, she wasn't even anywhere near my school at all.

Implications and Conclusions

We postulate that the processes of memory and perception operate with an intermediate stage of encoding: the formation of descriptions of the information being sought (in the case of memory retrieval) or of the event being experienced (in the case of perception and memory acquisition). For memory retrieval, descriptions provide an initial specification of the information being sought, guide the memory search process, and help determine the criteria for verification of whatever records are retrieved.

These analyses suggest a set of experimental paradigms: both discriminability and recoverability of memory descriptions must be studied. One can equate studies of levels of processing with studies of levels of description and, hence, with memory discriminability. More work needs to be done on the efficacy of retrieval codes. A theory of discriminability is but half a theory: recoverability must also play an equally important role. In a similar fashion, successful remembering requires success at two parts of the retrieval task: recovery of the appropriate record and successful acceptance or evaluation of that record. Both depend upon the adequacy of the retrieval specification.

In summary, we propose that both acquisition and retrieval of information requires an intermediate process: the formation of a description. Memory performance is a joint product of both the discriminability and recoverability of descriptions. We propose that memory acquisition involves iterative cycles of processing in which memory records are elaborated and encoded based upon the interpretation of the event being experienced, upon considerations of future recoverability, and upon the nature of those memory records accessible at the time of acquisition and that thereby guide the encoding process. We propose that retrieval also involves an iterative process which attempts to recover a description of the information sought that will effectively discriminate among the many records within the memory system. An understanding of memory requires an understanding of both acquisition and retrieval, and this, in turn, requires studies of the recoverability and discriminability of descriptions.

Footnotes

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1. We realize that there are debates about the form of memory. Thus, our postulate that information is stored within records will not be acceptable to everyone. Nonetheless, we hold that the argument for records is extremely strong. If one assumes that memory has an associative nature (that one memory structure references, or points to, or in some way becomes related to another), then half the argument is over. Careful examination of the nature of the associations necessary between memory elements indicates that they must be directional and differential (there have to be several kinds of associations). Thus, at the least, memory records must contain triples of information: the current record, the type of association, and the record being associated. Even *wholistic, nondiscrete* structural proposals for the process of memory must meet these properties. Thus, although the associative structures studied by Kohonen (1977) and by Anderson (1977; see also Anderson, Silverstein, Ritz, & Jones, 1977) look non-discrete and, therefore, not representable by discrete memory records, they are <u>functionally</u> and <u>analytically</u> so representable.

2. At the least, search involves going to the relevant material within memory and making it available for further processing. At the most, it requires sustained, systematic traversal of memory structures. There are various possible forms of search processes, from computation of appropriate memory locations, to systematic storage and examination procedures, indexing procedures, random examination, or spreading activation through a network of structures. We do not need to take a position on which procedure might best characterize human processes: all can be characterized within the general class of search processes.

3. Index mechanisms provide a special case of access through descriptions. Content addressable or pattern-matching retrieval systems are other forms of access through descriptions. Our ideas on discriminability were originally shaped by papers on library retrieval (Salton, Wong, & Yang, 1975; Salton, Yang, & Yu, 1975). Both Moscovitch & Craik (1976) and Fisher & Craik (in press) discuss the discriminability of memory records, and they trace the concept to Koffka (1935). Klein & Saltz (1976) also propose that

discriminability is a critical concept.

4. Note that according to our formalism for descriptions, subjects need not show distortions if their further specification and elaboration of the image points out the discrepancies from the prototype. Indeed, one could expect that the elaboration could play a larger role than the prototype. Thus, if (in the manner of numerous experiments in the Gestalt tradition), subjects were shown a circle with a gap in it, they could encode it as "a form of circle," elaborated as "with a break located at ...." At the time of reproduction, the gap could disappear (if the prototype were emphasized) or could enlarge (if the alternative elaboration were emphasized). Errors of subjects do indeed tend to go in both these directions. Of course, a theory that predicts deviations in all possible directions is rather weak in that it can account for whatever happens. What is needed, therefore, is some form of experiment in which biases toward prototypes or toward elaborations can be specifically induced and controlled.

5. The studies of FLOW were performed at the University of California, San Diego with Donald R. Gentner. The studies of POET were performed at the Xerox Palo Alto Research Center with Ross Bott, Donald R. Gentner, Serge Larochelle, Michael D. Williams, (University of California, San Diego), Allen Newell (Carnegie-Mellon University), and Stu Card, Tom Moran (Xerox).

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